Fundamentals in Ecology

Week 3

Adaptation to the Environment

–

Physiological Ecology

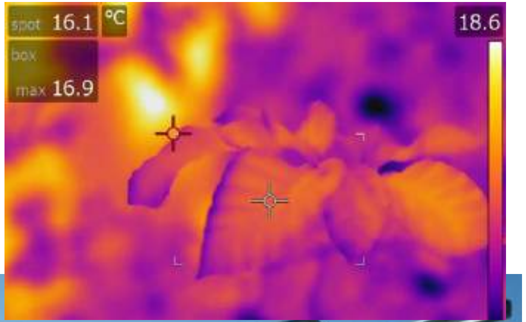
Grossiord Charlotte

Bachelor 2 - SIE

The Plant Ecology Research Lab - PERL

Our goal: Understand and predict climate change impacts on forests



https://www.epfl.ch/labs/perl/

Schedule of the lectures

Room for all lectures:

ELD020

WEDNESDAY - LECTURES - ENV 220			Week	Teacher
19/2/2025	10h15-12h	The nature of ecology (introduction)	1	T. Battin
26/2/2025	10h15-12h	The physical environment	2	T. Battin
5/3/25	10h15-12h	Adaptations to the environment/Physiological ecology	3	C. Grossiord
12/3/25	10h15-12h	Population structure, dynamics, and regulation	4	C. Grossiord
19/3/25	10h15-12h	Community Ecology I	5	C. Bachofen
26/3/2026	10h15-12h	Community Ecology II	6	C. Grossiord
2/4/26	10h15-12h	Ecosystem ecology I	7	T. Battin
9/4/26	10h15-12h	Ecosystem ecology II	8	T. Battin
16/4/2026	10h15-12h	Biodiversity and conservation ecology	9	C. Grossiord
23/4/2025	Easter Holiday			
30/4/2025	ENAC Week			
7/5/24	10h15-12h	Climate Change impacts on terrestrial ecosystems	10	C. Grossiord
14/5/2024	10h15-12h	Climate Change impacts on aquatic ecosystems	11	T. Battin
21/5/2025	10h15-12h	Restoration ecology. Principles of ecosystem restoration, case studies	12	T. Battin
28/5/2025	10h15-12h	Applied ecology. Review and course wrap-up	13	C. Grossiord

Schedule of the practicals

Look at the schedule provided by your group (terrestrial *vs*. aquatic).

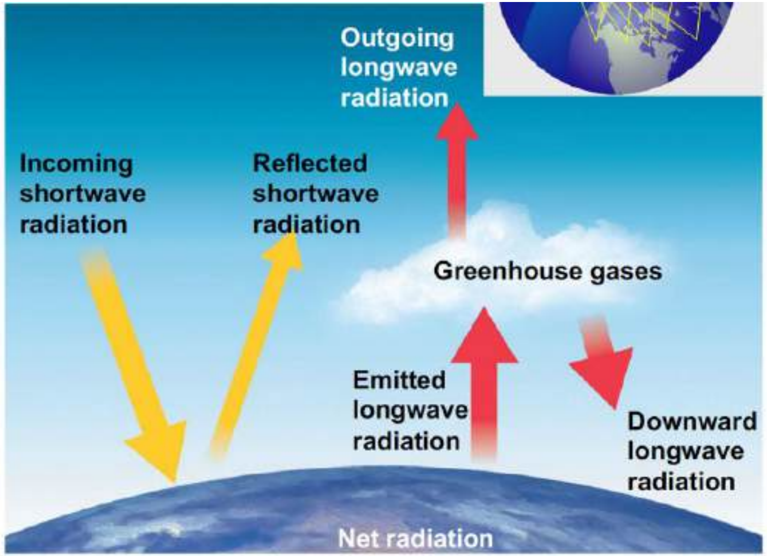
Regularly verify the information on Moodle

THURSDAY - PRACTICALS - ENV 220			Week	Important deadlines
20/02/25	11h15-13h	Introduction to practicals	1	
27/02/25	11h15-13h	Setting up experiments	2	Inform the experimental setup to TAs by email by 26/02/25
6/3/25	11h15-13h	How to write a report	3	
13/03/25	11h15-13h	Introduction to R	4	
20/03/25	11h15-13h	Field measurements 1	5	
27/03/25	11h15-13h	Data visualization in R	6	
3/4/25	11h15-13h	Field measurements 2	7	
10/4/25	11h15-13h	How to do statistical analyses	8	
17/04/25	11h15-13h	Field measurements 3	9	
24/04/25	Easter Holiday			
1/5/25	ENAC Week			
8/5/25	11h15-13h	Field measurements 4	10	
15/05/25	11h15-13h	Data Analysis/Interpretation	11	Weighting of plant material in GR B2 423 before 15/05/25
22/05/25	11h15-13h	Questions / Discussion	12	
REPORT SUBMITTED on MOODLE BY 06/06/25				

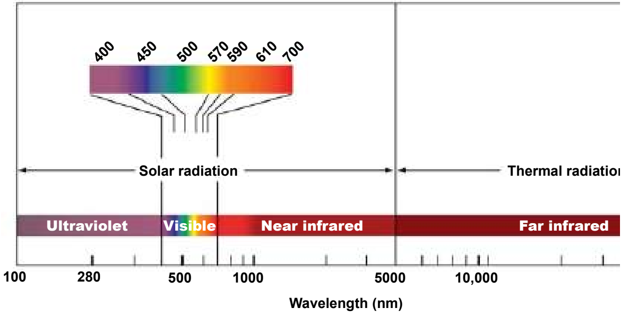
What you saw in the previous lecture

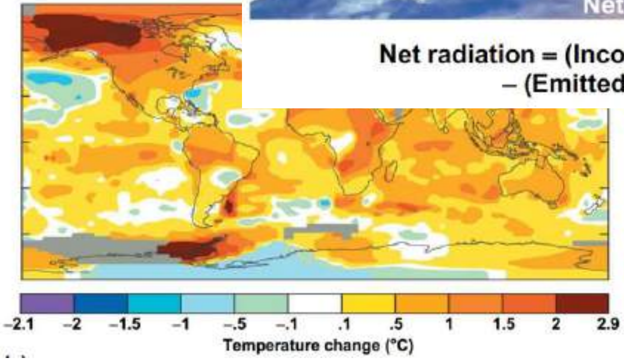
The physical environment

Recap of key principles such as radiation, temperature, precipitation distribution… across the globe



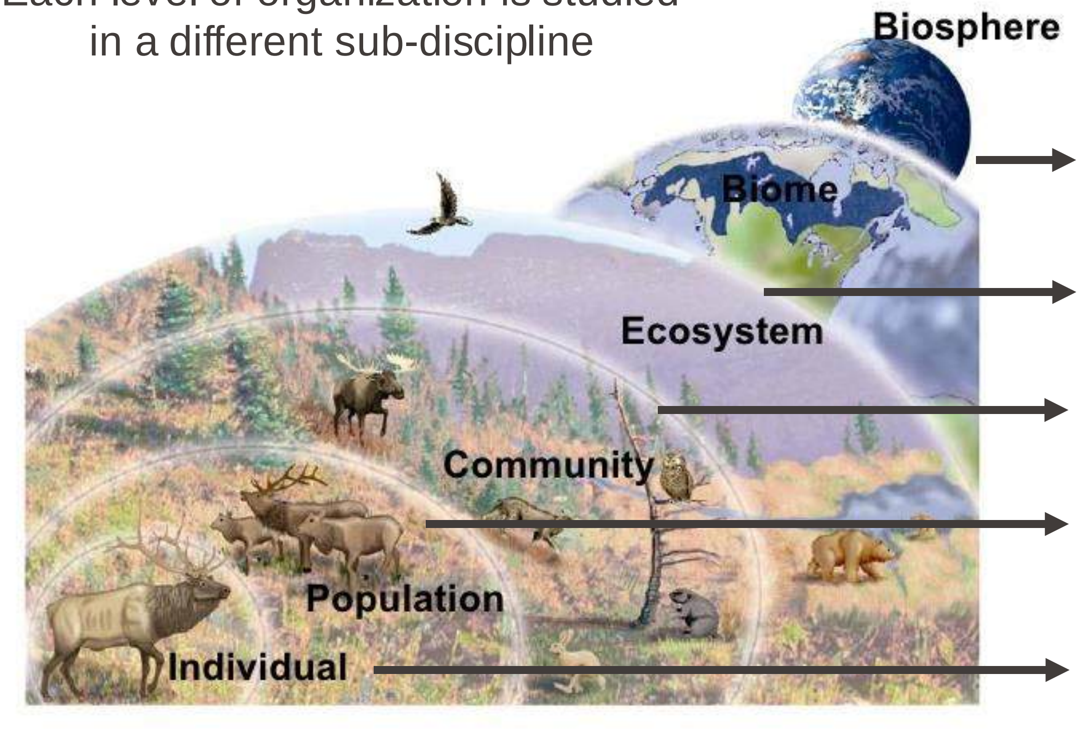
Net radiation = (Incoming SW – Reflected SW) – (Emitted LW – Downward LW)





Levels of organization in ecology

Each level of organization is studied in a different sub-discipline



Global change ecology & Biogeography

Ecosystem ecology

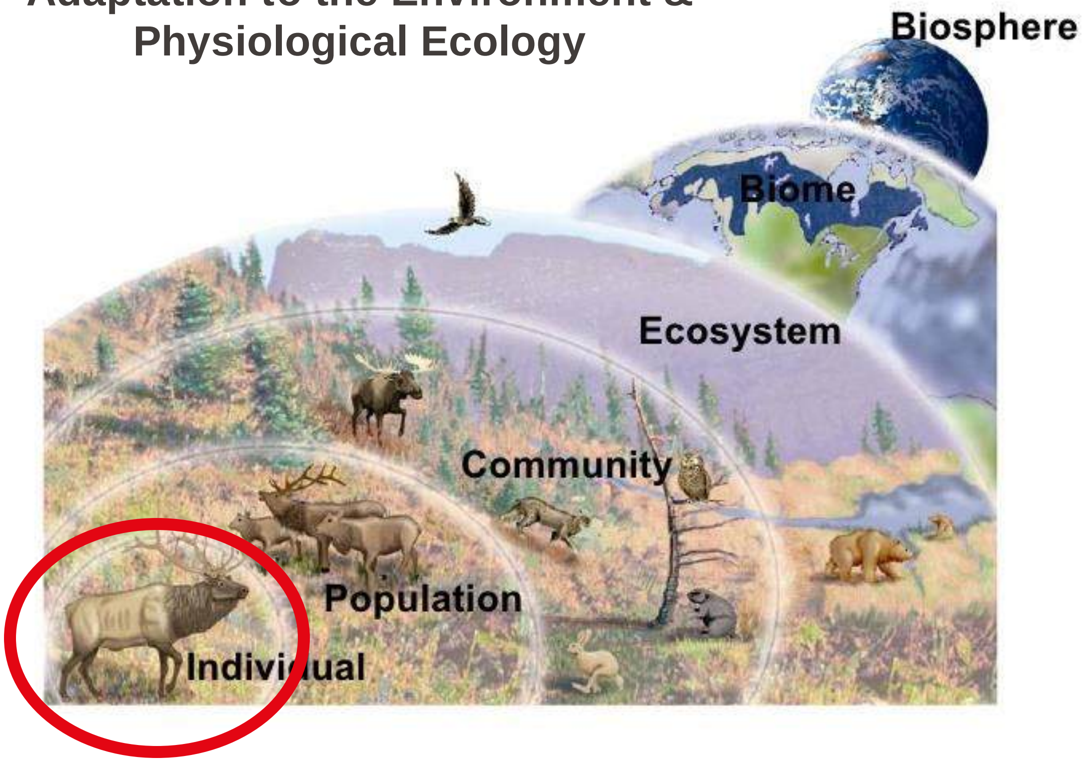
Community ecology

Population ecology

Evolutionary ecology and physiology

Overview of today's class

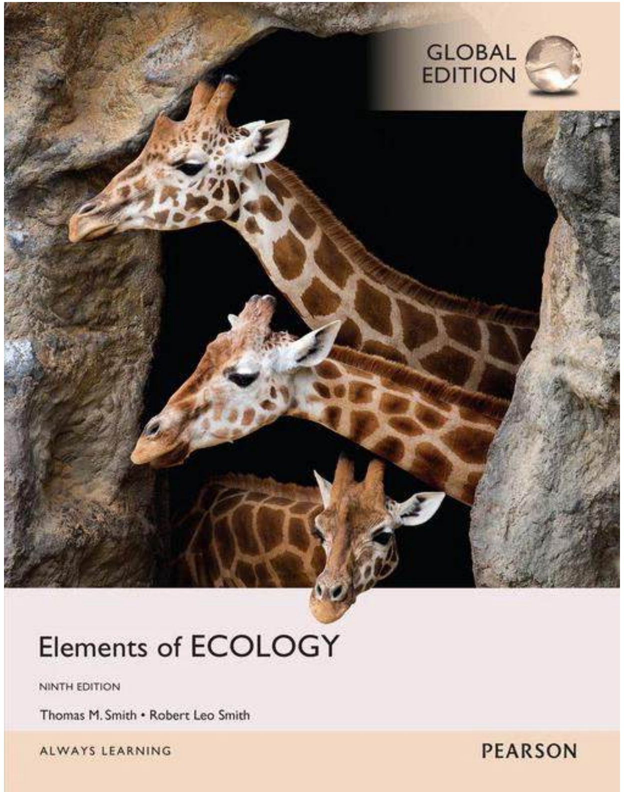
Adaptation to the Environment &
Physiological Ecology



I. Adaptation and natural selection

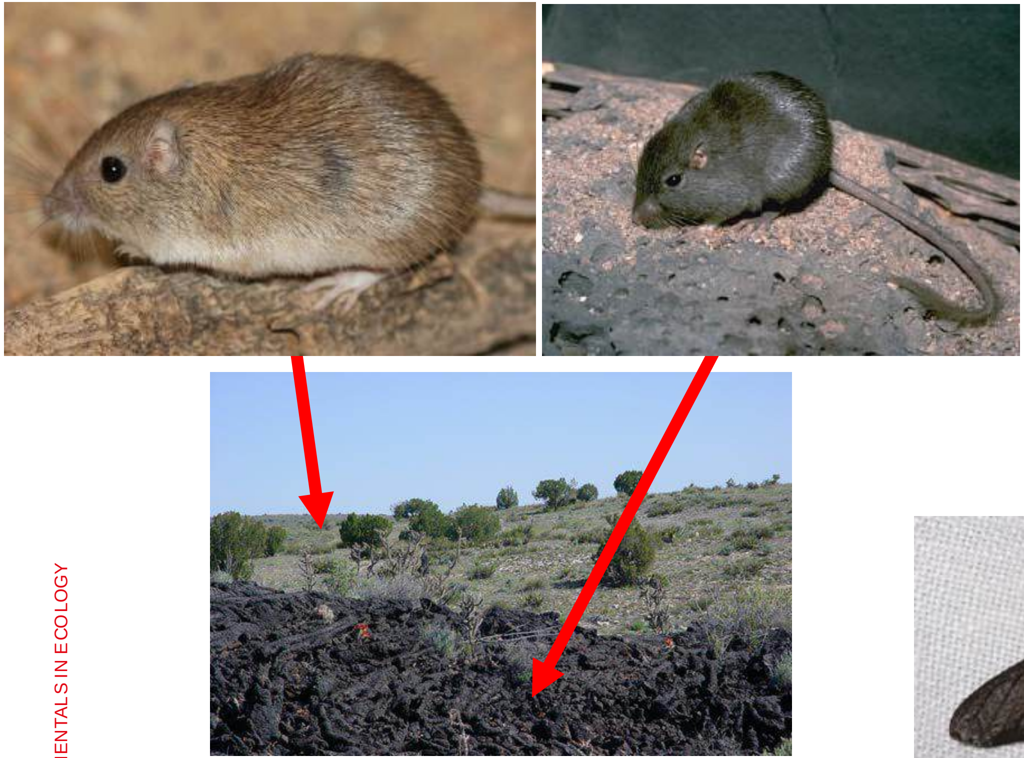
II. Plant physiological ecology

References to today's class



Smith, TM. & Smith RL. Elements of Ecology, Global Edition (Pearson)

1. Adaptation and natural selection

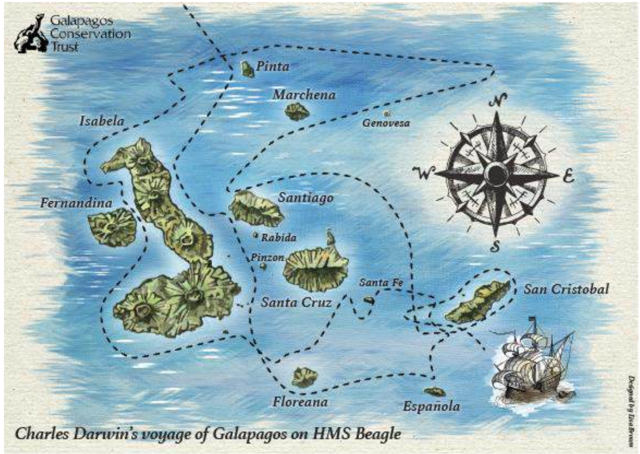


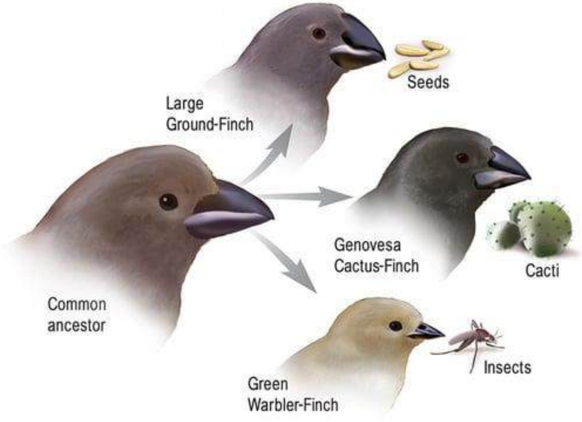
The rock pocket mouse

The Peppered Moth

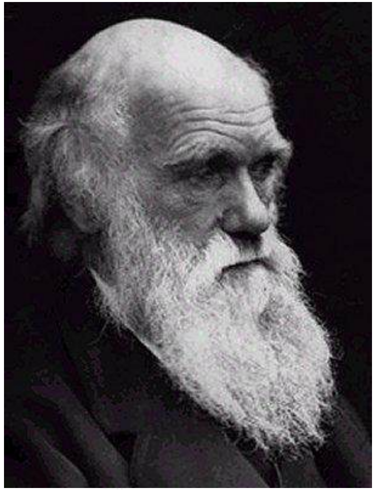
1. Adaptation and natural selection

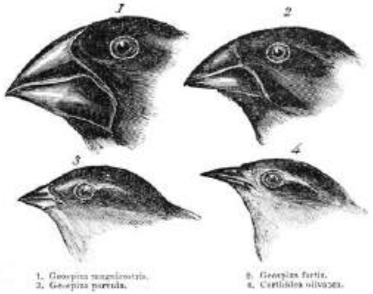
Charles Darwin proposed **the theory of natural selection** to describe how organisms adapt to their environment.





Charles Darwin (1809-1882)

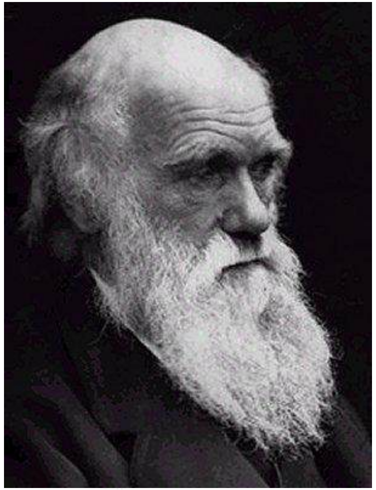




Galápagos finches

1. Adaptation and natural selection

Charles Darwin (1809-1882)

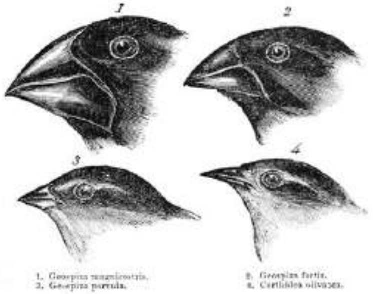


Charles Darwin proposed **the theory of natural selection** to describe how organisms adapt to their environment.

Natural selection = differential success (i.e., survival and reproduction) of individuals within a population that results from interactions with their environment.

Two conditions are required:

- variation in a characteristic/trait must be **heritable**
- variation in a characteristic/trait leads to differences in **survival and reproduction** among individuals within the population through interactions with the environment.



Galápagos finches

1. Adaptation and natural selection

Natural selection, survival of the fittest Herbert Spencer (1864)

In a given environment, individuals with characteristics/traits that confer higher rates of survival and reproduction have more offspring. Those characteristics are more frequent in the next generation.

Evolution = the process of natural selection which results in changes in the characteristics/traits of populations of organisms over the course of generations.

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Natural selection = differential success (i.e., survival and reproduction) of individuals within a population that results from interactions with their environment.

1. Adaptation and natural selection

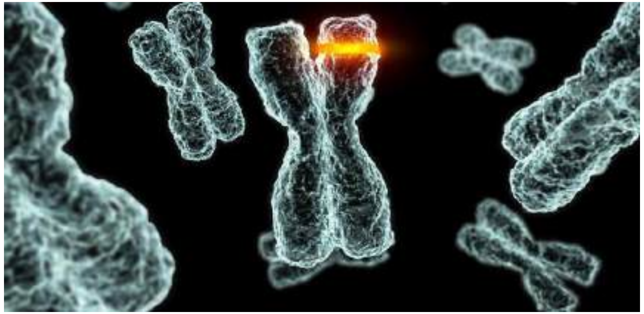



Adaptation = heritable behavioral, morphological, or physiological trait that has evolved through the process of natural selection. Adaptation maintains or increases the fitness of an organism under a given set of environmental conditions.

The study of the relationship between organisms and their environment is the study of adaptation and the key to understanding the distribution and abundance of species.

1. Adaptation and natural selection

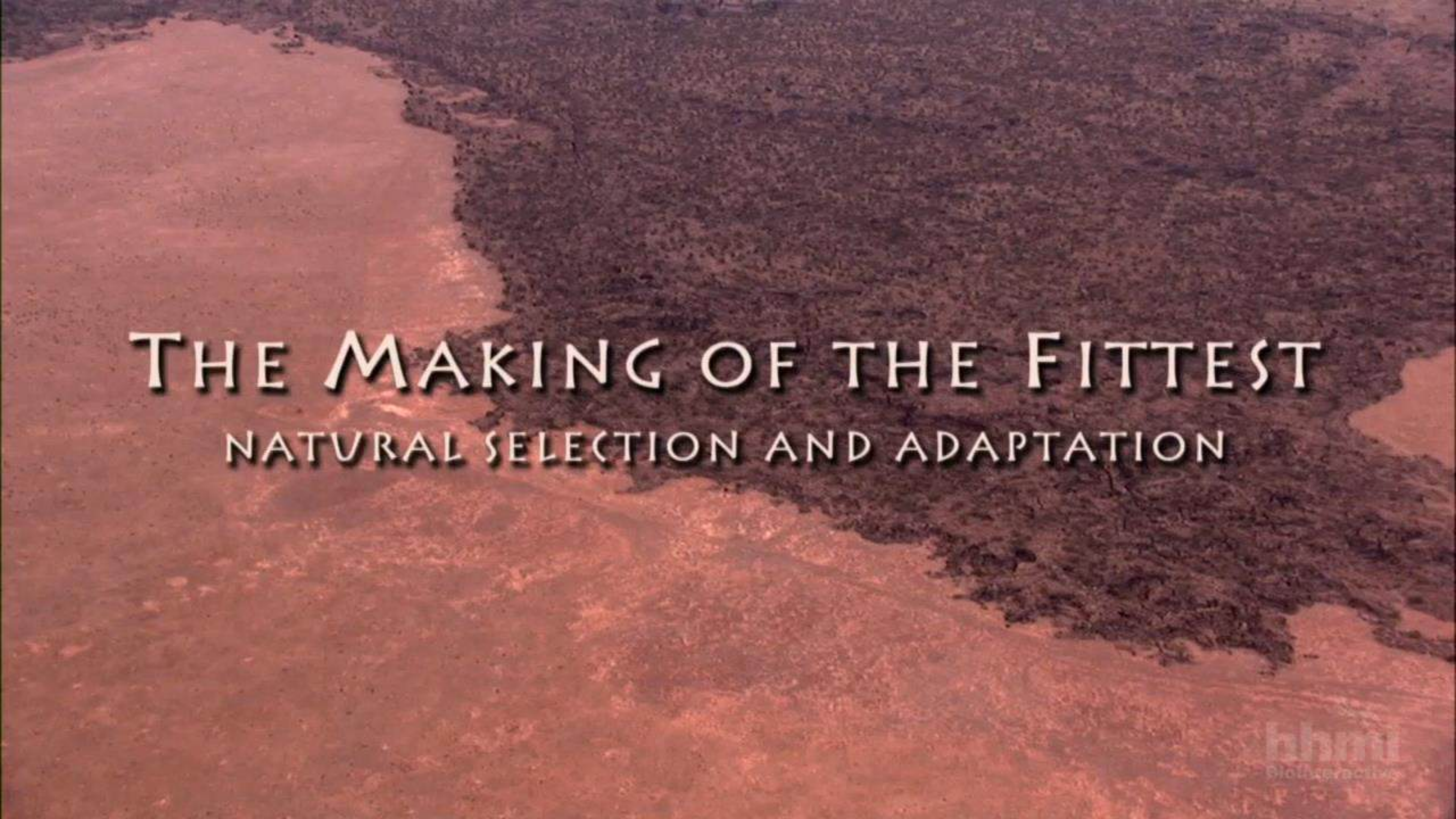
Adaptations are traits that are **inherited** – passed from parent to offspring.



Mutations are heritable changes in a gene, and the ultimate source of genetic variation that natural selection acts upon.

Mutation is a **random** force in evolution, producing genetic variation.

Whether a mutation is beneficial depends on the environment. Harmful mutations are removed by natural selection.


THE MAKING OF THE FITTEST
NATURAL SELECTION AND ADAPTATION

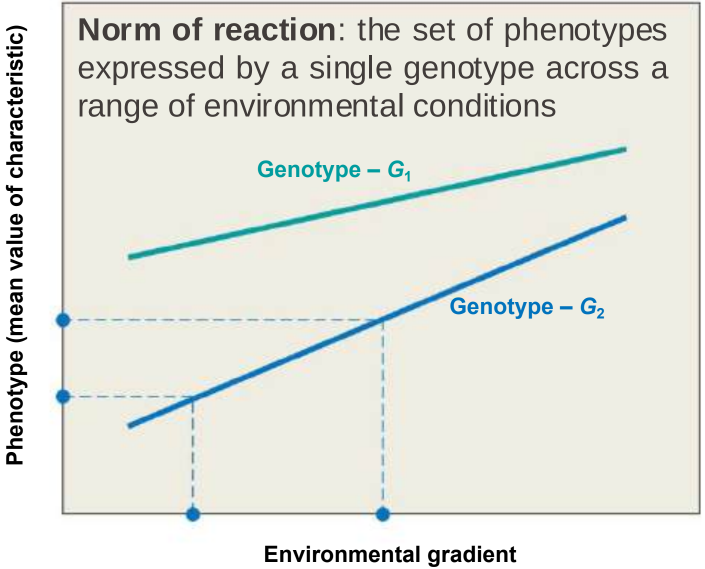
1. Adaptation and natural selection

Utetheisa ornatrix bella

The **phenotype** is the outward appearance of an organisms for a given characteristic (the external, observable expression of the genotype).

The phenotype can vary with the environment:

- Environmental conditions vary continuously (e.g., daily variation in temperature, precipitation, sunlight, predation level).
- Changes in the environment can cause the phenotype produced by a given genotype to vary continuously - **phenotypic plasticity**



1. Adaptation and natural selection

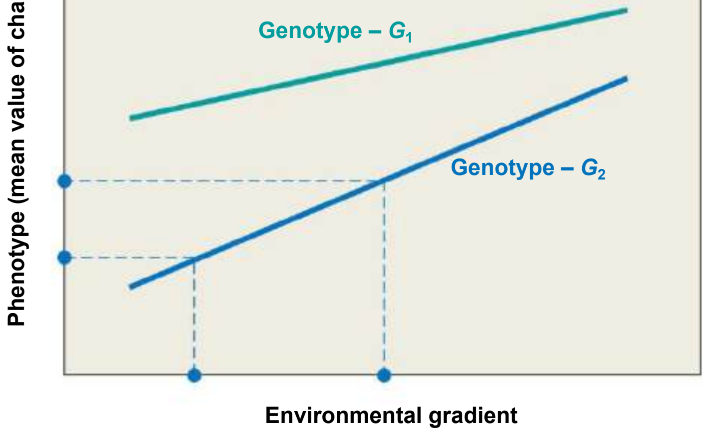
This is what you will be measuring in the practicals

Interpreting Ecological Data:

- Which of the two genotypes (G_1 or G_2) exhibits the greater plasticity?

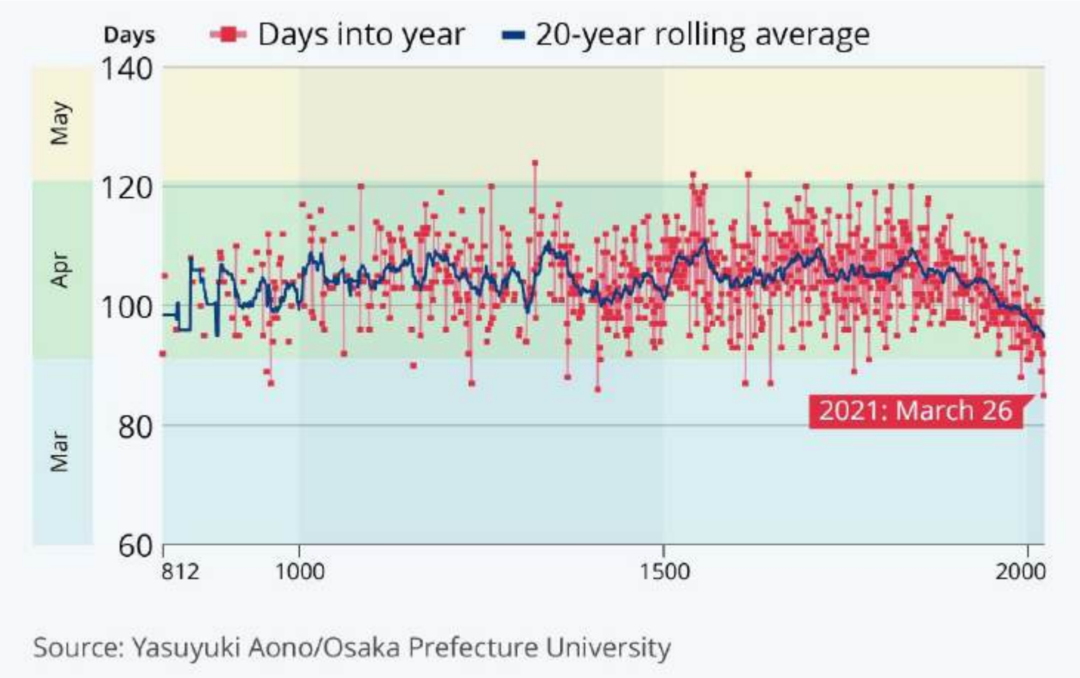
- Is it possible for the two genotypes to express the same phenotype?

Norm of reaction: the set of phenotypes expressed by a single genotype across a range of environmental conditions



1. Adaptation and natural selection

Reversible phenotypic changes in response to changing environmental conditions are called **acclimation**.

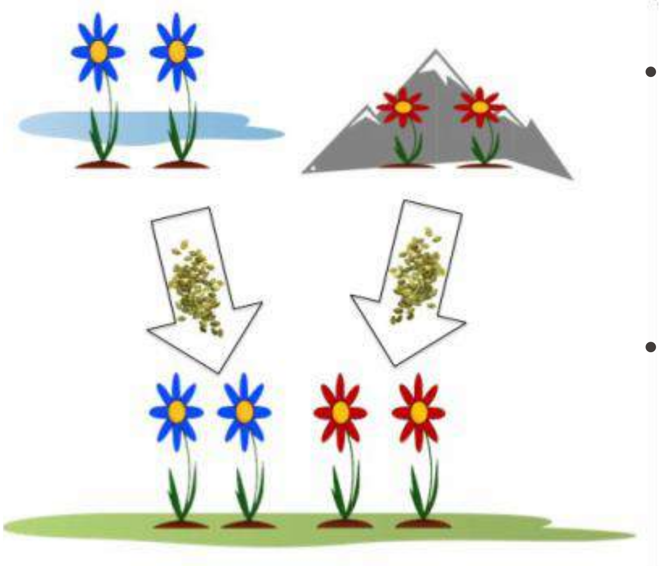


Cherry-blossom peak-bloom changes yearly depending on air temperature (earlier with warmer temperatures).

1. Adaptation and natural selection

So, what is the difference between adaptation and acclimation? How can we test it?

Common garden experiments - take individuals from different populations and grow them under the same, controlled environmental conditions (in the same garden).



- If the plants from the different populations are genetically distinct, planting in the same common garden will result in plants with different phenotypes.

- If the plants from the different populations are genetically the same but exhibiting phenotypic plasticity, planting in the same common garden will result in plants with the same phenotype.

1. Adaptation and natural selection

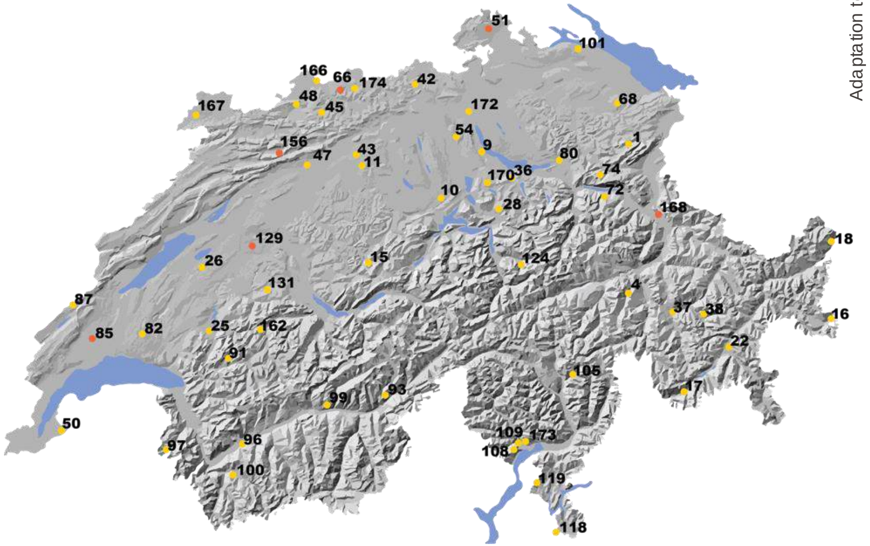
Common garden experiments in Switzerland

A. alba

F. sylvatica

Swiss Federal Institute for Forest, Snow and Landscape Research WSL

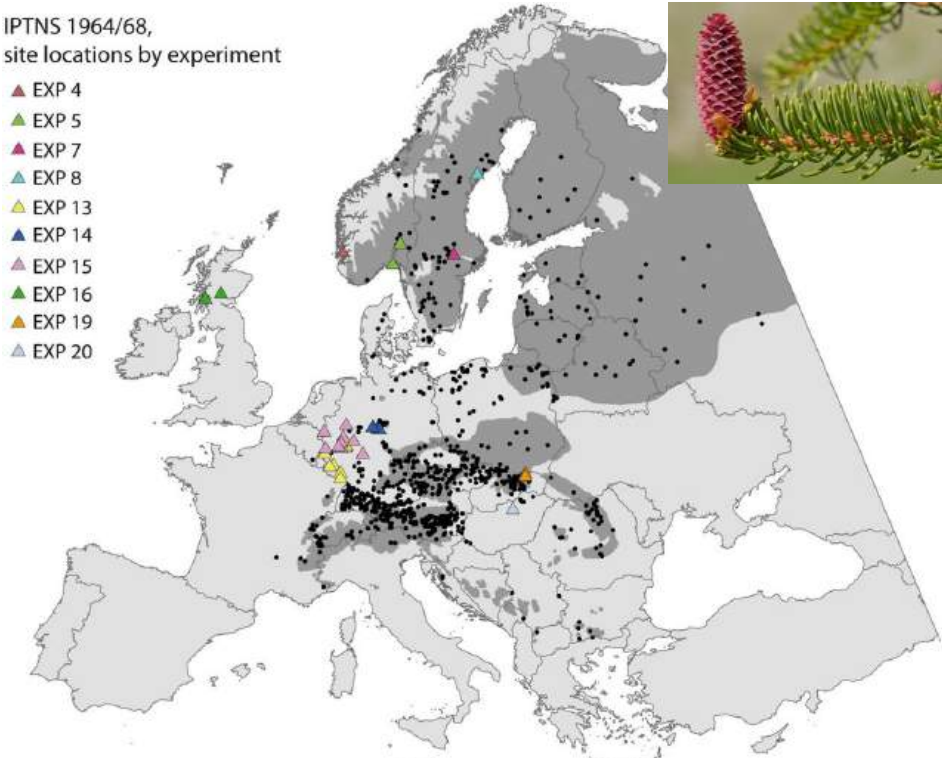
The Swiss common garden network of future tree species



57 sites planted with 18 tree species

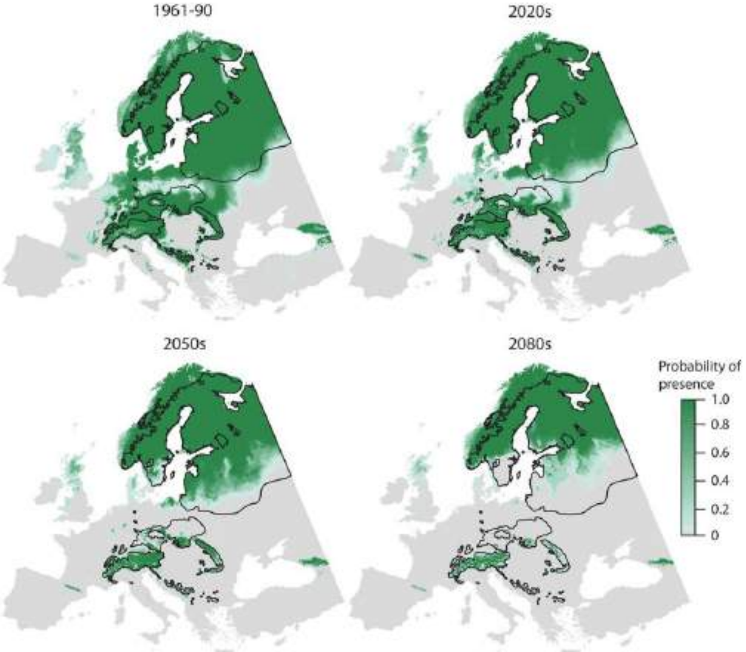
1. Adaptation and natural selection

Common garden experiments in Europe



Liepe et al. (2022) Frontiers

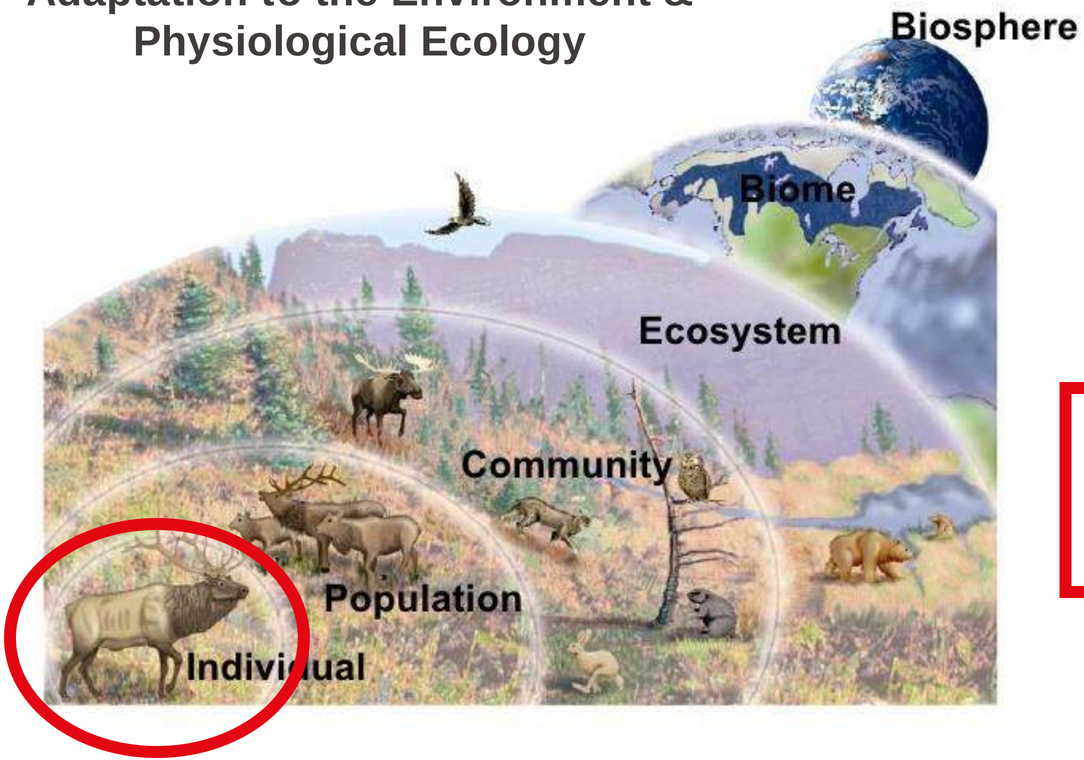
Probability of presence of Norway spruce



Sampled populations (black points) of the International Provenance Test 1964/68 of Norway spruce (IPTNS). The natural distribution of Norway spruce is shaded in dark gray

Overview of today's class

Adaptation to the Environment & Physiological Ecology

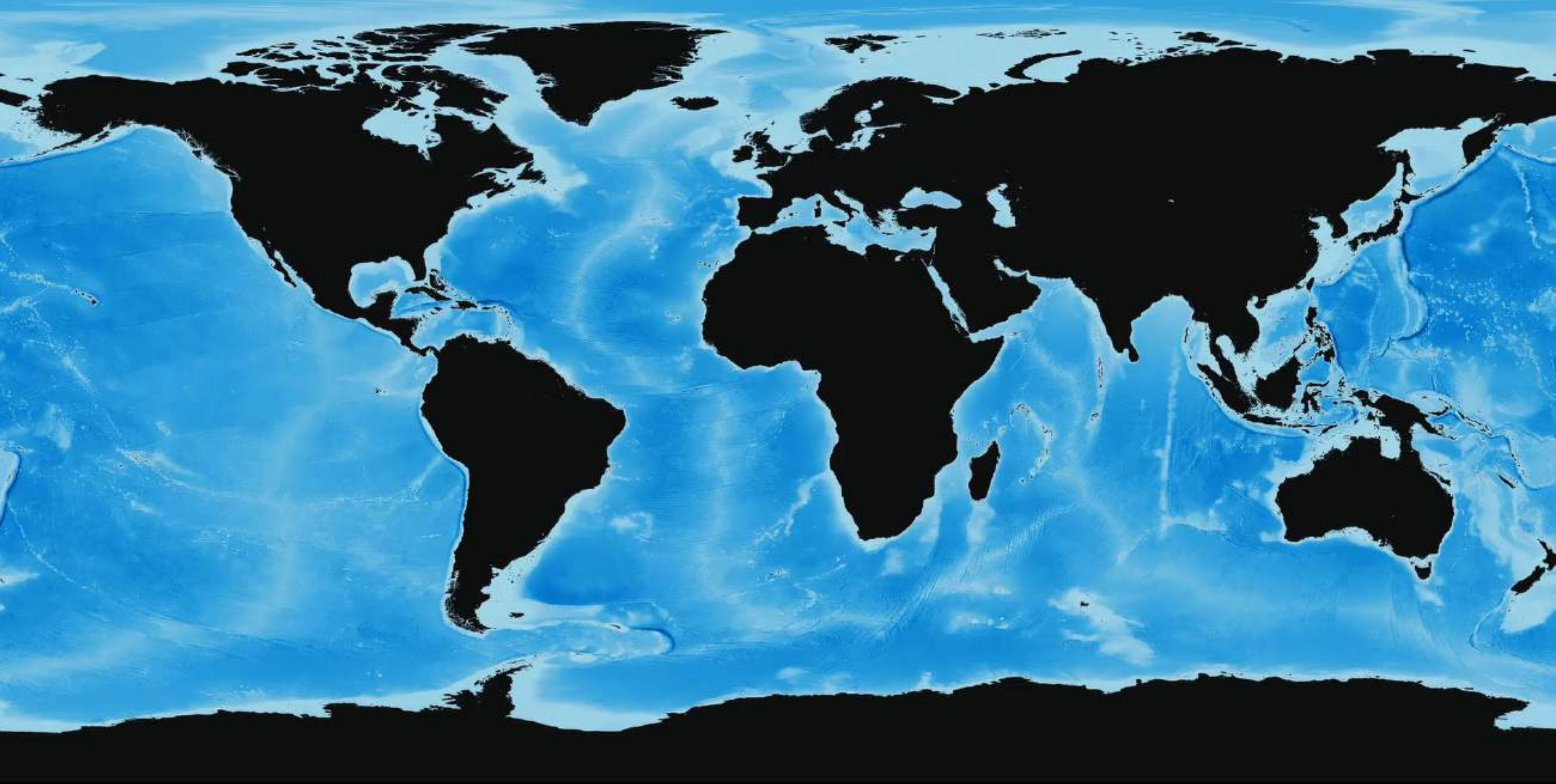


I. Adaptation and natural selection

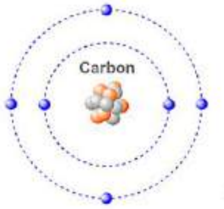
II. Plant physiological ecology

2. Plant physiological ecology

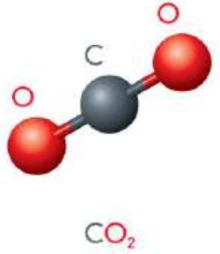
Plants have adaptations to help them survive in different areas. This explains why certain species are found in one area, but not in another.



2. Plant physiological ecology



All life on Earth is carbon based – all living creatures are made up of complex molecules built on a framework of carbon atoms.

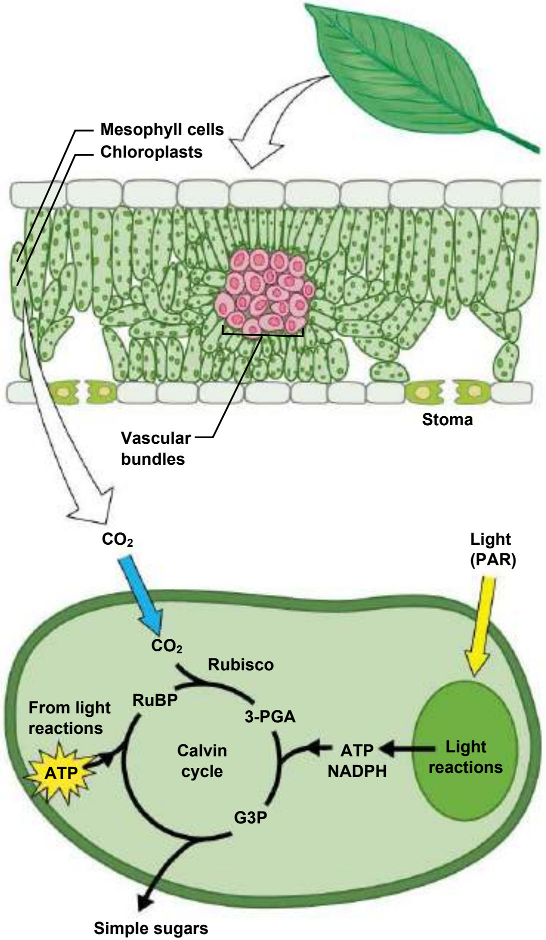


The source of carbon from which life is constructed is carbon dioxide (CO_2) in the atmosphere. Only **autotrophs** can transform carbon in the form of CO_2 into organic molecules and living tissue.

Photoautotrophs use the Sun's energy to drive the process of converting CO_2 into simple organic compounds.

That process, carried out by green plants, algae and some type of bacteria is called **photosynthesis**.

2. Plant physiological ecology



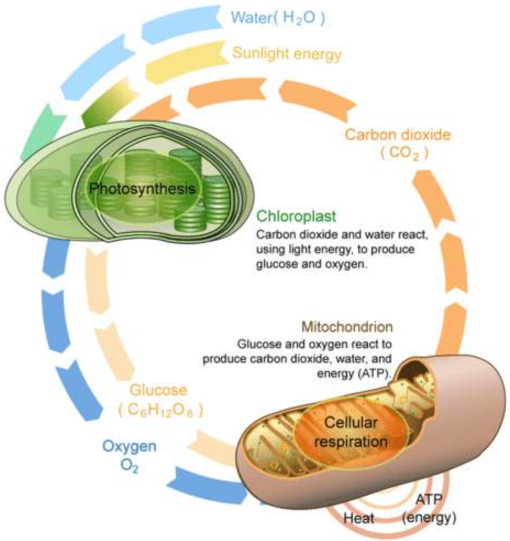
Photosynthesis - a series of reactions that result in the fixation of CO_2 into carbohydrates :

$$6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Photosynthesis occurs in the mesophyll. **Chlorophyll** is a pigment in the chloroplasts that absorbs light energy in the 400–700 nm range (**Photosynthetically Active Radiation, PAR**).

Sugars and complex carbohydrates are made mainly in the leaves. They are required for plant growth and maintenance.

2. Plant physiological ecology



Plants use **cellular respiration** to release energy (ATP, adenosine triphosphate) from the sugars produced during photosynthesis:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + ATP$$

Respiration to produce ATP occurs during the dark (night-time), but CO_2 release can also occur during the day (a stress response referred to as photorespiration and caused by excess of light)

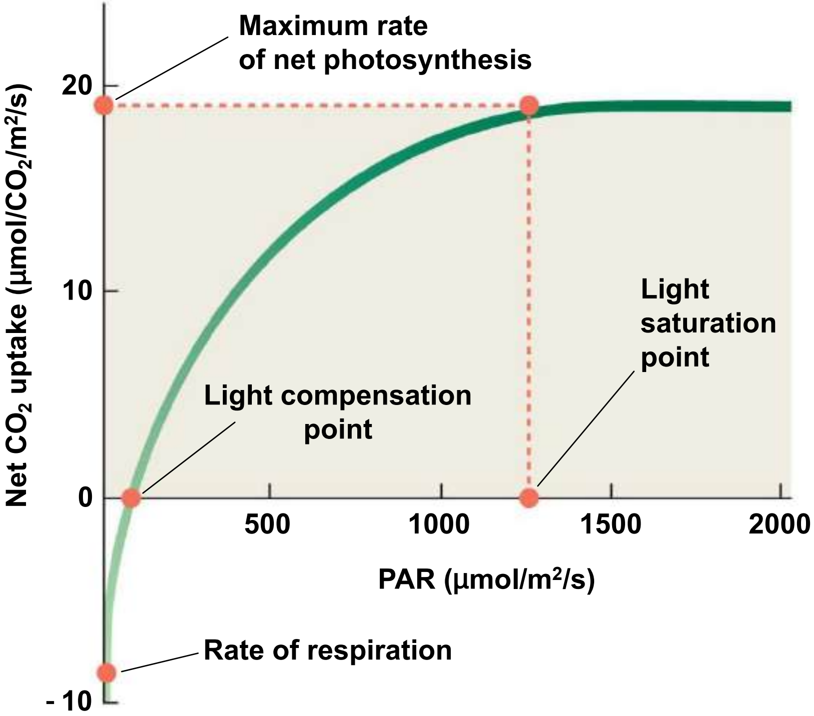
Gross photosynthesis (μmol $CO_2/m^2/s^{-1}$) = total amount of CO_2 that plants fix through the process of photosynthesis

$\neq$

Net photosynthesis (μmol $CO_2/m^2/s^{-1}$) = Gross photosynthesis - Respiration

2. Plant physiological ecology

The availability of light directly influences the rate of photosynthesis:

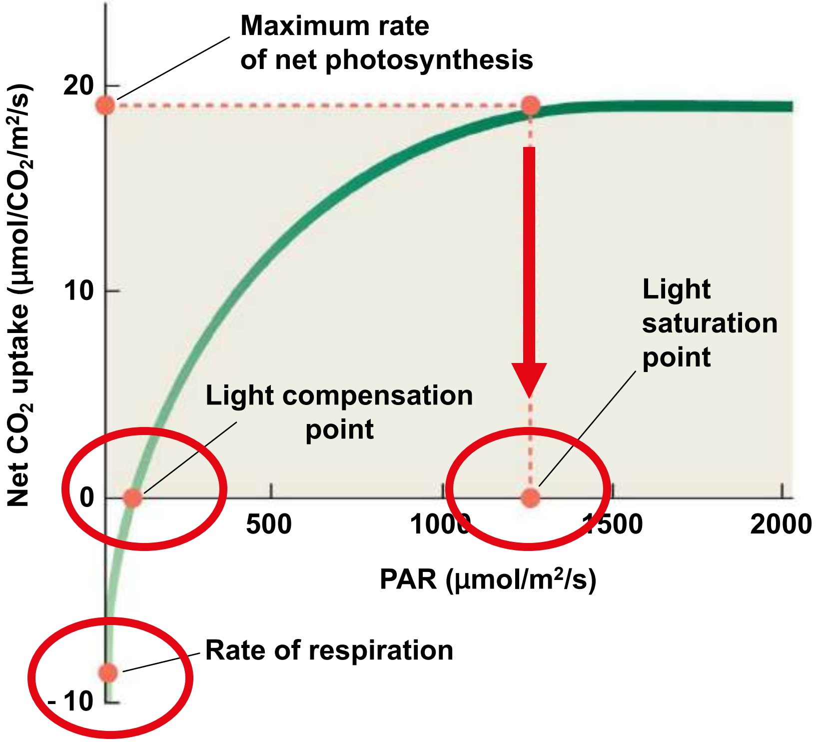


Response of net photosynthesis to available light (PAR)

2. Plant physiological ecology

The availability of light directly influences the rate of photosynthesis:

- When PAR = 0, only respiration occurs. CO_2 is lost (net uptake is negative). As PAR increases, the rate of photosynthesis increases.
- The **light compensation point (LCP)** is the light level (PAR) at which CO_2 uptake in photosynthesis = CO_2 loss in respiration (the rate of net photosynthesis is zero)
- The **light saturation point (LSP)** is the value of PAR above which photosynthesis does not increase (maximum rate of net photosynthesis).



Response of net photosynthesis to available light (PAR)

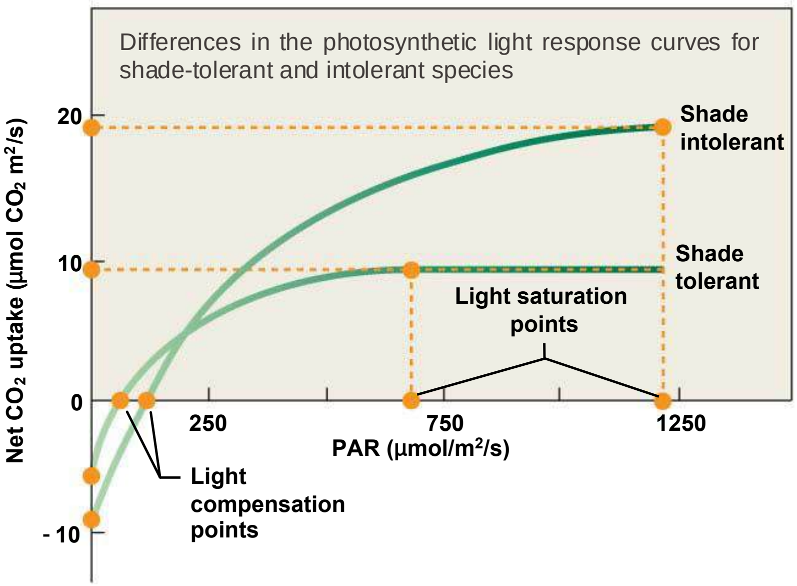
2. Plant physiological ecology

Plants have evolved to possess a range of physiological and morphological adaptations to survive and grow in different light regimes.

- **Shade-intolerant plants** – adapted to high-light
- **Shade-tolerant plants** – adapted to low-light

EPFL

2. Plant physiological ecology

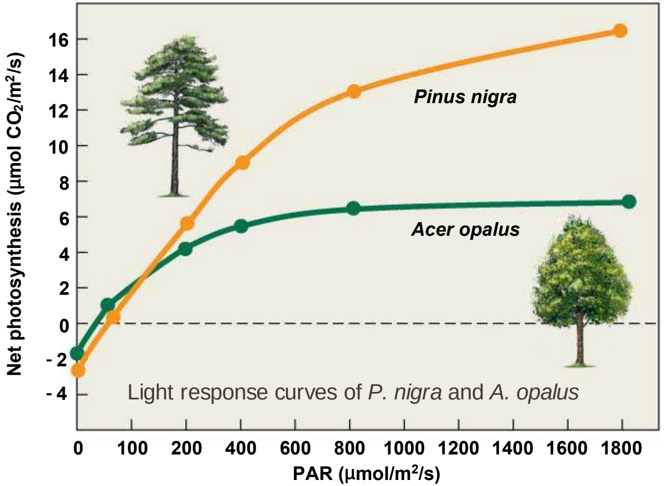


Show fundamental differences in patterns of photosynthesis in response to different light levels

Shade-tolerant plants have higher specific leaf area (SLA) and lower leaf thickness than intolerant ones.

P. nigra

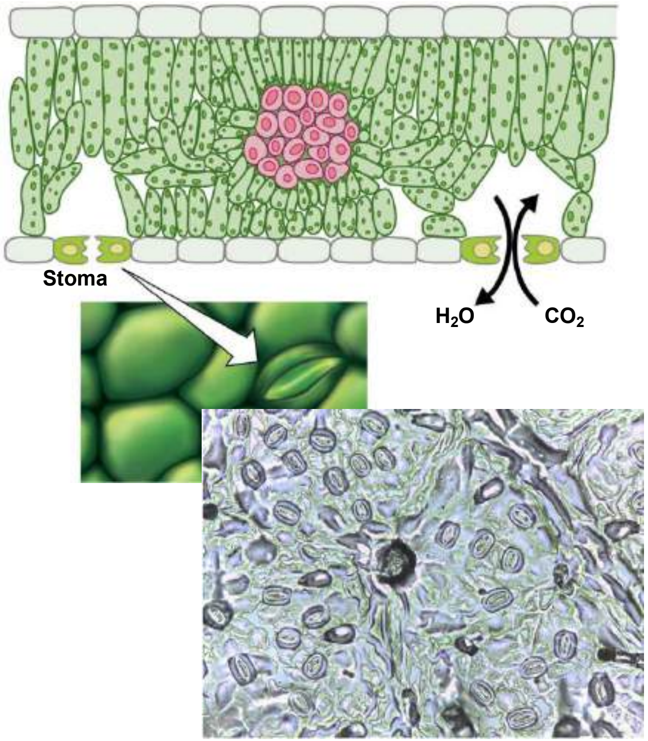
A. opalus



Light response curves of *P. nigra* and *A. opalus*

2. Plant physiological ecology

For photosynthesis to occur, CO_2 must move into the leaf. Gas diffuses from higher concentration in the air (about 420 ppm of CO_2) to lower concentration in the leaf.



Stomata – openings on the leaf surface that allow CO_2 to enter

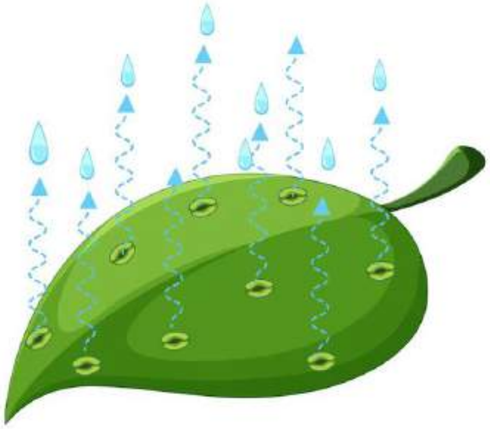
Two factors control the diffusion of CO_2 into the leaf:

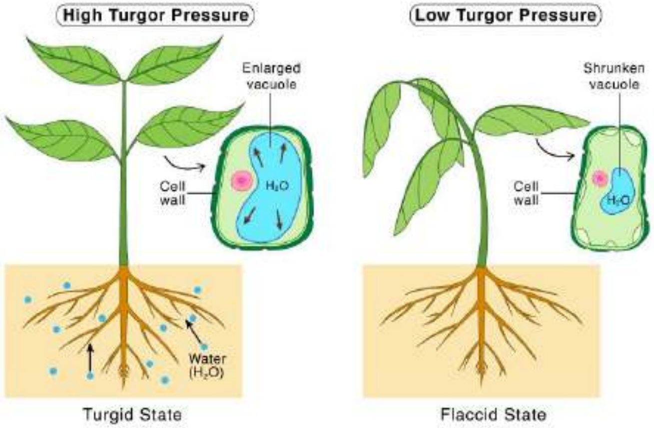
- The diffusion gradient (difference between [CO_2] inside and outside the leaf).
- Stomatal conductance (the flow rate of CO_2 through the stomata, $\mu mol/m^2/s^{-1}$). Conductance depends on stomatal density and aperture.

2. Plant physiological ecology

When the stomata are open, water vapor in the leaf diffuses out – a process called **transpiration**. It depends on:

- The relative humidity inside a leaf is usually saturated compared to the air (diffusion gradient).
- The lower the relative humidity of the air outside the leaf, the larger the diffusion gradient and the more rapidly the water will diffuse out of the leaf.





Turgor pressure is the force exerted outward on a cell wall by the water inside the cell. Plants function best when their cells are fully hydrated (at maximum turgor).

2. Plant physiological ecology

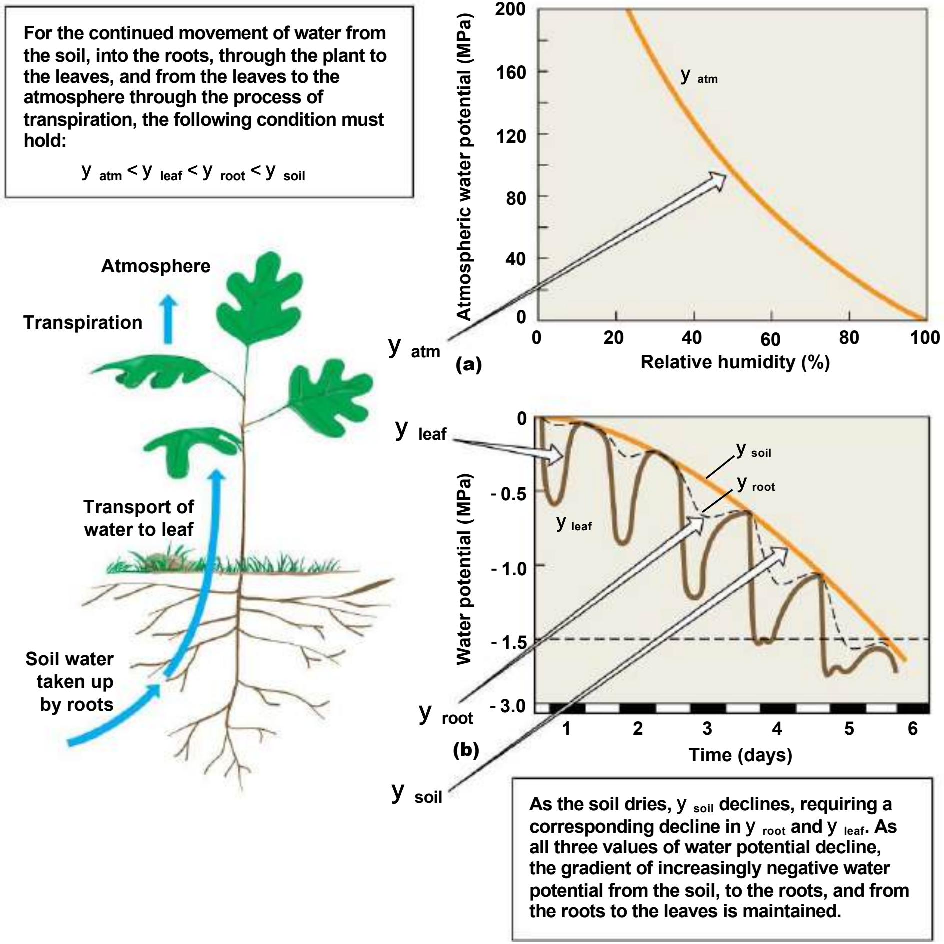
Water movement through the soil-plant-atmosphere continuum (SPAC) occurs passively following differences in water potential.

Water potential (ψ, Pa = 1 Newton m^{-2}): water energy at any point in the SPAC.

At field capacity, ψ_{soil} is close to zero. As water is taken from the soil, ψ_{soil} becomes more negative (water holds more tightly to the soil)

Stomata close at night and ψ_{leaf} is less negative because water is not lost.

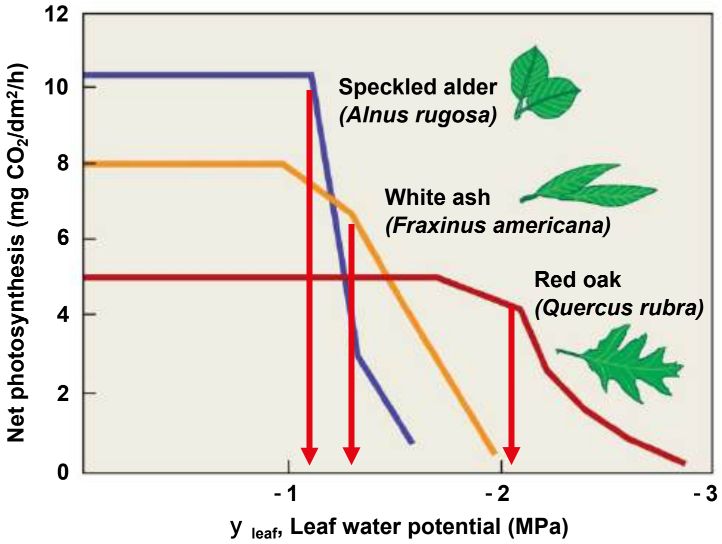
ψ_{atm} depends on the relative humidity of the atmosphere.



2. Plant physiological ecology

If the soil is dry, stomata close to prevent water loss and photosynthesis stops.

The value of ψ_{leaf} at which photosynthesis stops varies between species, reflecting different adaptations.



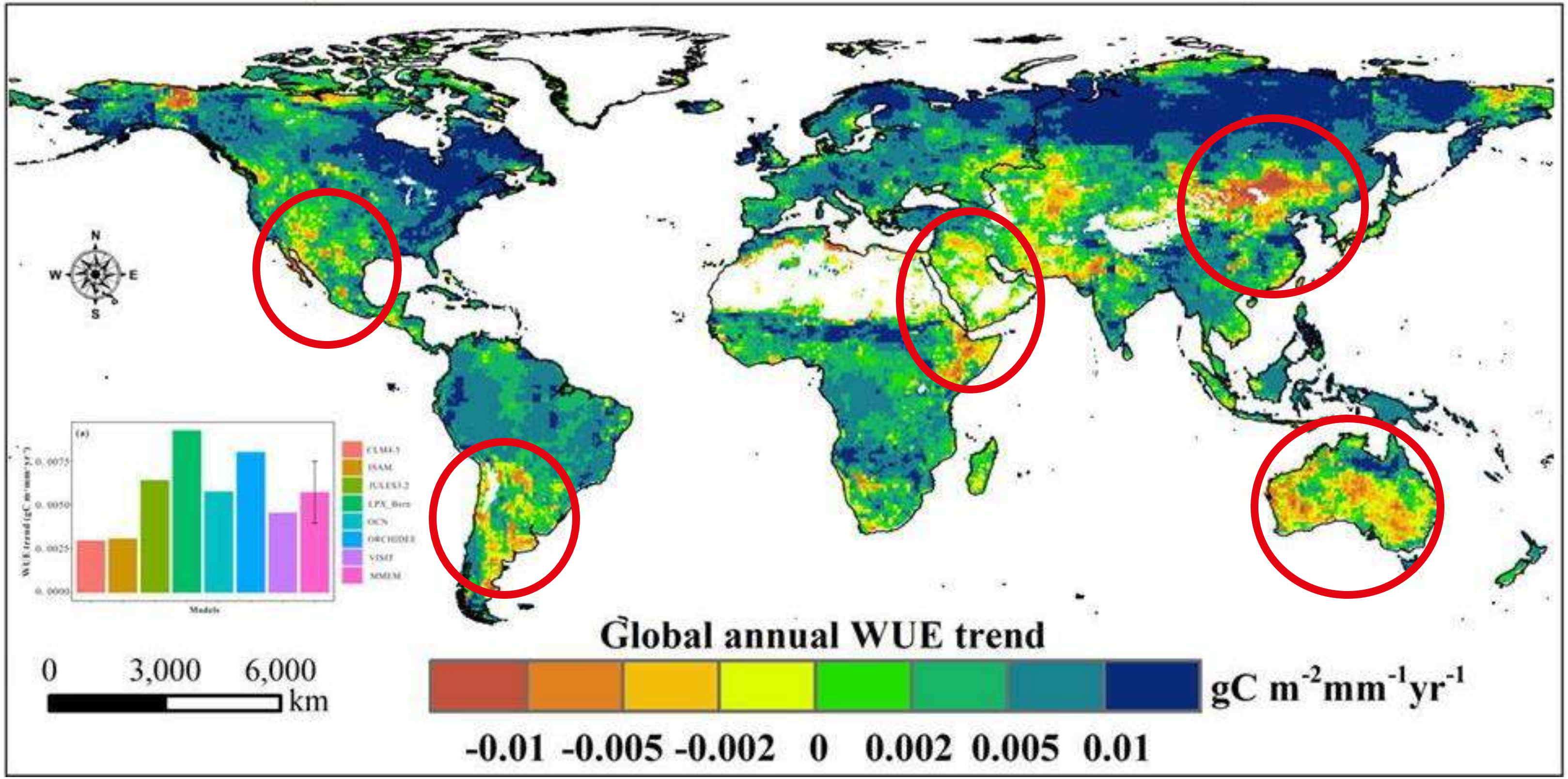
Changes in net photosynthesis as a function of leaf water potential for three tree species from the northeastern United States.

Controlling the stomata aperture is a plant's most important way to regulate water loss. This leads to a trade-off between taking in CO_2 for photosynthesis and losing water through transpiration.

Water use efficiency (WUE) = the ratio of carbon fixed per unit of water lost.

2. Plant physiological ecology

WUE is higher in drier places

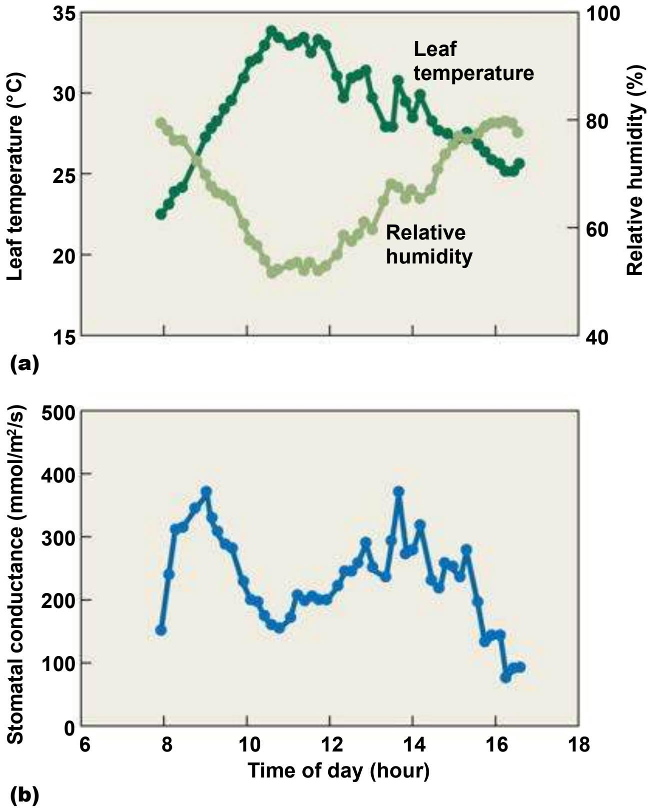


Liu et al., 2020; STOTEN

2. Plant physiological ecology

As temperature rises, relative humidity decreases, which increases transpiration. Consequently, plants close their stomata to avoid water stress, thereby also limiting photosynthesis (and growth).

- Some plants respond to moisture stress by curling leaves or shedding them to reduce water loss and heat gain.



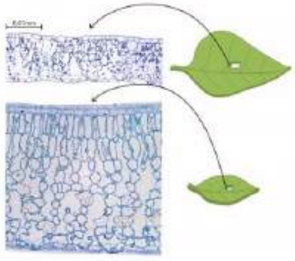
Diurnal changes in (a) temperature, relative humidity, and (b) stomatal conductance measured at the top of the canopy of *Fagus crenata* (Japanese beech).

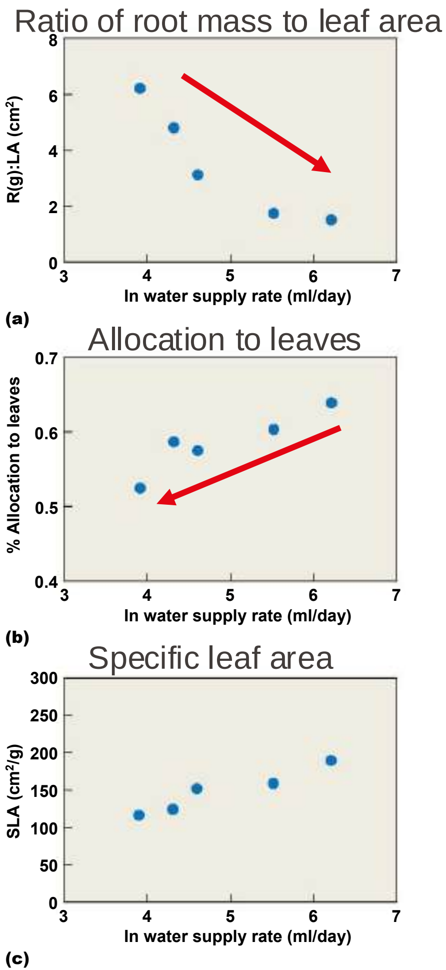
2. Plant physiological ecology

During drought and heat, photosynthetic inhibition reduces the production of chlorophyll. Carbon allocation is increased for the production of roots and decreased for the production of leaves **(cf. practicals).**

- As water availability decreases, plants allocate more carbon to producing roots than leaves.
- This increased allocation to roots increases the surface area of roots for the uptake of water, whereas the decline in leaf area decreases water loss through transpiration.

Eucalyptus dives



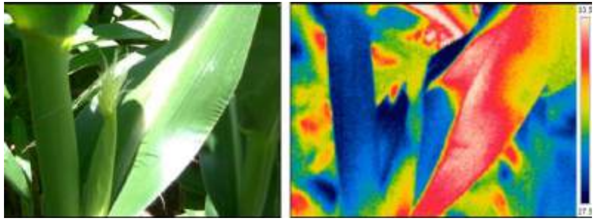


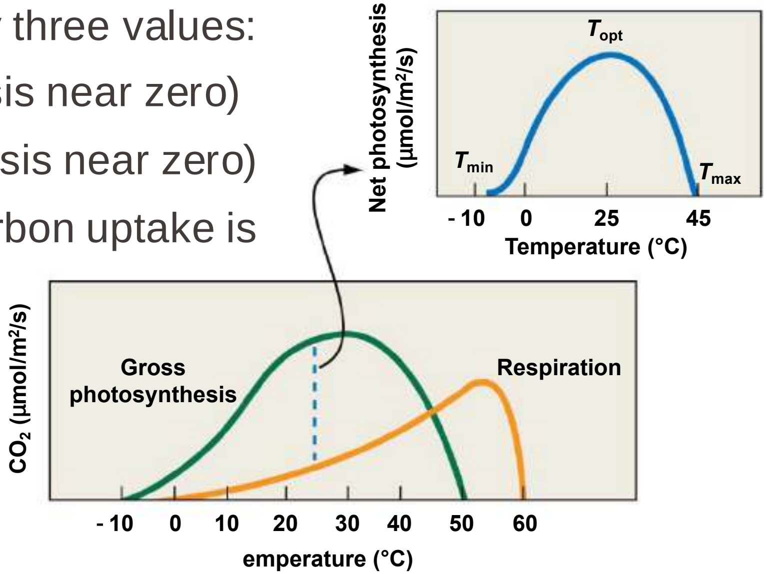
2. Plant physiological ecology

Both photosynthesis and respiration respond to temperature variation, increasing as temperature increases.

A temperature response curve is described by three values:

- T_{min} = minimum temperature (net photosynthesis near zero)
- T_{max} = maximum temperature (net photosynthesis near zero)
- T_{opt} = range of temperatures over which net carbon uptake is highest





Leaf temperature determines the rates of these two processes. Leaf temperature is driven by the energy it receives from the radiation and the surrounding air temperature.

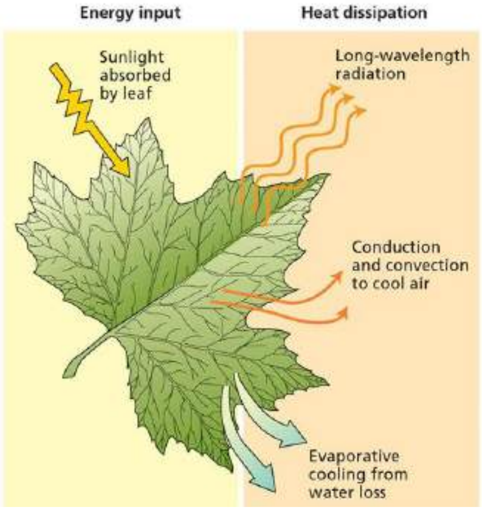
2. Plant physiological ecology

To maintain conditions for positive net photosynthesis plants must exchange heat with the air through **convection** and **evaporation.**

Emit thermal radiation - radiate longwave infrared radiation (thermal energy) back to the cooler surroundings (atmosphere)

Convection - the transfer of heat energy through the circulation of fluids (air/water)

Evaporation - water transpires from the leaves and thermal energy is lost. The higher the rate of transpiration, the greater the evaporative cooling.

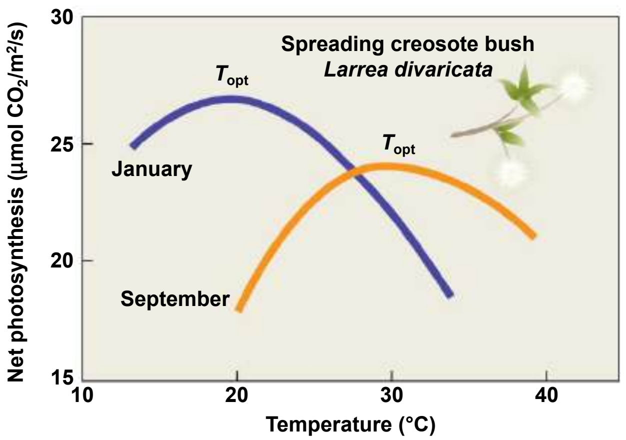


2. Plant physiological ecology

Plants can acclimate to varying environmental conditions.

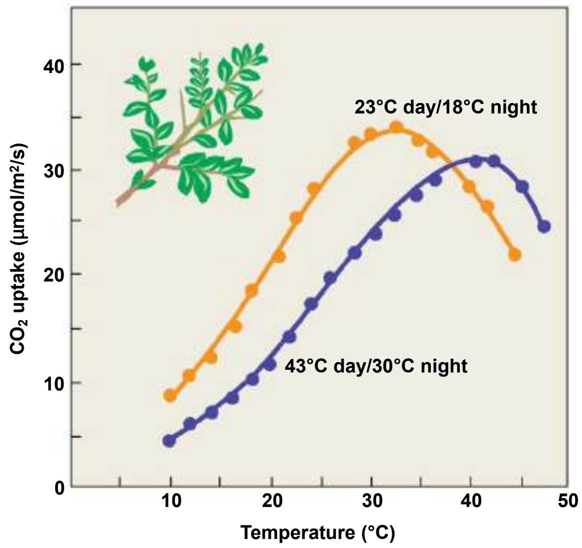
For example, when individuals of the same species are grown at different temperatures, divergence in temperature response of photosynthesis is often observed:

- T_{opt} is lower for plants grown under cooler conditions
- T_{opt} is higher for plants grown under warmer conditions



Seasonal shift in the relationship between net photosynthesis and temperature for creosote bush shrubs growing in the field.

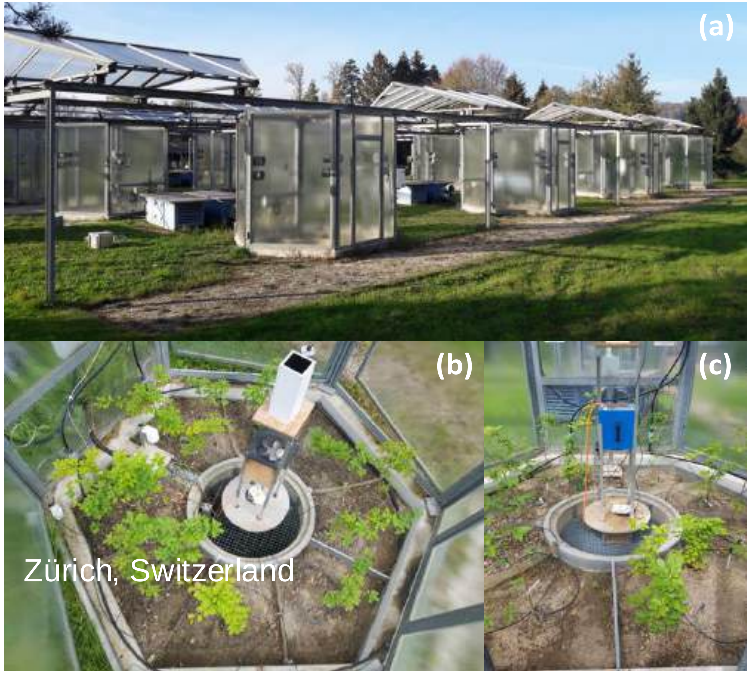
The same shift can be observed with seasonal changes.



Relationship between temperature and net photosynthesis for plants of big saltbush grown under two different day/night temperature regimes.

2. Plant physiological ecology

Experimental design



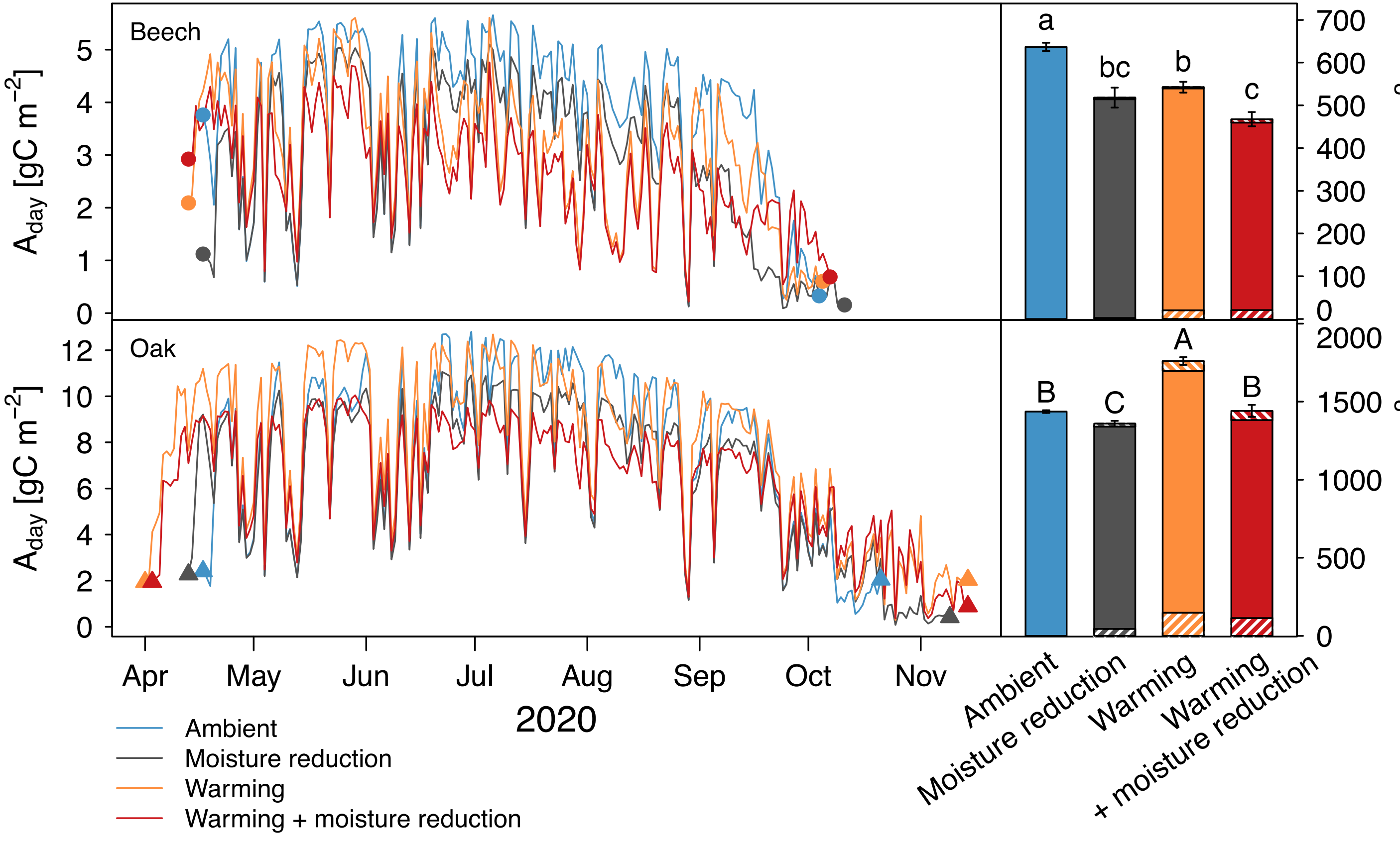
Phenology

Photosynthesis

16 open-top chambers subjected to heat, drought or heat+drought

2. Plant physiological ecology

SPAC modeling of leaf-level photosynthesis

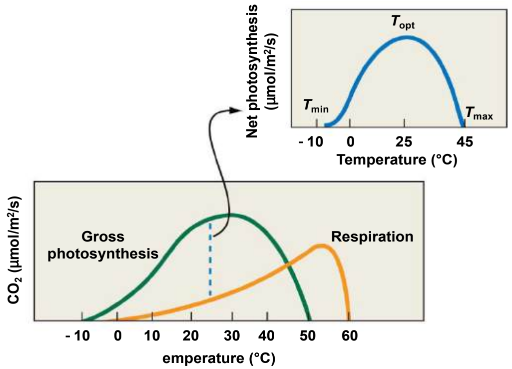


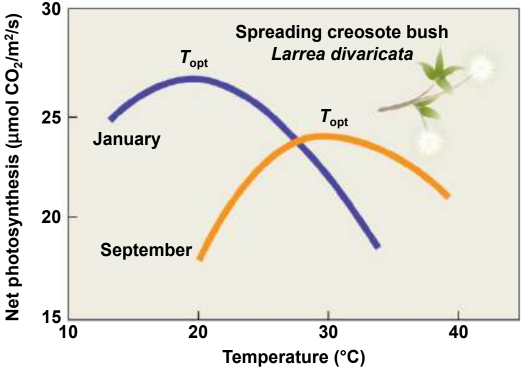
3. Exercices

Question: Compare how gross photosynthesis, respiration and net photosynthetic rates change with temperature, and describe how these responses change seasonally between cold and warm periods. Use one or more graphs in your answer.

At the exam in 2022

<u>Answer:</u> As can be seen in the graph, both gross photosynthesis and respiration respond to temperature variation, increasing as temperature increases. The response of gross photosynthesis follows a parabolic curve while respiration increases until an optimum and decreases rapidly passed this threshold. The difference between gross photosynthesis and respiration is net photosynthesis. Net photosynthesis follows a parabolic curve with an optimum (corresponding to Topt). Tmin and Tmax correspond to the minimum and maximum temperature at which photosynthesis is close zero.





In the case of <u>warm-weather conditions, the optimum temperature will be shifted towards higher temperature while for cold conditions, Topt will take place at colder temperatures</u>. This type of response is the result of phenotypic plasticity (when comparing one species under different conditions) or adaptation (when comparing different species in different environments). This is what is represented in the figure below showing the net photosynthesis response to temperature of *Larrea divaricate* plants in January *vs.* September.

3. Exercices

Short Answer Questions (*at the exam in 2023*)

1) _________ is the differential success of individuals in a population in response to environmental conditions.

Answer: Natural selection

2) The measure used to describe the free energy of water at any point along the soil-plant-atmosphere continuum is called its _________.

Answer: Water potential

EPFL

3. Exercices

EPFL *Bachelor SIE – Fundamentals in Ecology – Written exam 24th of June 2024* Page 1/5

Exam questions – Fundamentals in Ecology

Indicative time: 40-60 minutes
(PLEASE WRITE CLEARLY AND IN A STRUCTURED MANNER)

Student last name: ______________	**First name:** ______________
SCIPER: ______________	
Examiner: Charlotte Grossiord	Grade: / 40 points

Short Answer Questions (1 point per question / 10 questions in total)

1) ____________ is the process of natural selection resulting in changes in the traits of populations over the course of generations.
Answer: Evolution

2) The process of using the sugars produced during photosynthesis to produce energy for cellular activities is called ____________.
Answer: Respiration

3) A species with a high distribution range is referred to as ____________.
Answer: Ubiquitous

4) ____________ are the random variation in the environment that can influence birthrates and death rates in a population.
Answer: Environmental stochasticity

5) ____________ reflects how equally individuals are distributed among species in a community.
Answer: Species evenness

6) A ____________ is a functional classification of organisms in a community or ecosystem according to their feeding relationships.
Answer: Trophic level

7) ____________ is the species diversity of individual communities.
Answer: Alpha diversity

8) Globally, species diversity ____________ as you move northward and southward from the equator.
Answer: Decreases/declines

9) Over the past 600 million years, the overall trend in the number of species has been____________.

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Environmental Sciences and Engineering (SIE) / SIE - Bachelor

Fundamentals in ecology

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General Collapse all

In this class, you will learn the fundamentals of ecology with the goal to perceive the environment beyond its physical and chemical characteristics. Starting from basic concepts, you will acquire a mechanistic understanding of biodiversity, ecosystem functioning, and global change. This course will combine both theoretical and practical parts.

Go on Moodle to see last year's exam with or without corrections

Next week

Populations